Alternative Cropping Systems Alter Residual Weed Community Composition

A.G. Thomas[1], J.Y. Leeson[1], S.A. Brandt[2]

[1]Agriculture and Agri-Food Canada, Saskatoon Research Centre, Saskatoon, SK, S7N 0X2
[2]Agriculture and Agri-Food Canada, Scott Research Farm, Scott, SK, S0K 4A0

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Abstract

Weed community composition was assessed in 1994 through 2000 in the Alternative Cropping System Project at Scott, SK. Weeds were counted during July after in-crop management practices had been used. The weed community was composed of 67 species. The nine arable cropping systems in the project were compared in terms of weed frequency, density, and diversity. Changes in weed community composition over time are displayed as a principal response curve (PRC). This method compares the weed community in the cropping systems to a reference system. PRCs are based on redundancy analysis, a constrained form of principal components analysis. Weed densities are constrained to be linear combinations of the interaction of system and year. Seven years and initial spatial variation (4 replicates and 36 sub-plots) are removed as covariables. The PRC analysis identified problematic weed species associated with the cropping systems after six years. Green foxtail, lamb's-quarters and stinkweed were abundant in the three organic input systems. Wild oats, shepherd's-purse and narrow-leaved hawk's-beard were abundant in the reduced input systems. The three organic systems appear to have reached equilibrium after a three-year transition period. The problematic weed species in the reduced systems still appear to be increasing after six years.

Introduction

Sustainable land management is based on five pillars: productivity, security, protection, viability, and acceptability (Smyth and Dumanski 1993). The successful management of weed populations contributes to the five pillars for sustainability of arable crop production systems. The development and adoption of integrated management tactics for weed populations are limited by our current knowledge of how the weed community is influenced by the management practices involved in crop production systems. The Scott Alternative Cropping System Project was designed to evaluate the sustainability of crop production systems using a 16 ha experimental study site for a minimum of 18 years. The experimental framework is a matrix of three input levels and three cropping diversity levels. Combinations of input and diversity levels result in nine cropping systems. We hypothesized that differences in weed community composition would be expected in the nine cropping systems during the six-year rotational cycle because species are known to respond to alterations in tillage and herbicide inputs, competitiveness of crops grown in the rotations, and yearly variation in growing season precipitation. The specific objectives were to (a) describe the response of the weed community to changes in the cropping system, (b) use principal response curves to provide a concise summary of the temporal dynamics of the weed community in the nine cropping systems, and (c) examine the temporal dynamics of individual species in the nine cropping systems.

Cropping Systems

The low diversity rotation (LOW) is a traditional rotation of fallow-wheat-wheat-fallow-canola-wheat. The organic input level uses green manure fallow, the reduced input level has one green manure fallow and one chemical fallow, and the high input level has tillage fallow. The diversified annual grains rotation (DAG) has a diversity of cereal, oilseed and pulse grains. The reduced and high input systems follow the same rotation (canola-fall rye-pea-barley-flax-wheat), while the organic input system incorporates green manure fallow for nitrogen fixation (green manure fallow-wheat-pea-barley-green manure fallow-canola). The diversified annual and perennial rotation (DAP) mixes grains and perennials (canola-wheat-barley-oat under seeded to brome alfalfa-brome alfalfa-brome alfalfa).

Differences in weed management strategies for the three input levels are summarized in Fig. 1. Tillage operations are presented as average values per plot per year. Mounted tine harrows and trailed rod were not counted as separate tillage operations. Seeding and fertilizer banding were not included as tillage operations. Herbicide applications are presented as average values per plot per year. Tank-mixed herbicides were considered one application. The annual input intensity per plot per year is the sum of the tillage operations and the herbicide applications. Only tillage was used for weed management in organic systems (ORG), whereas herbicides were used almost exclusively in the reduced systems (RED). Both tillage and herbicides were used for weed management in high input systems (HIGH). Annual input intensity was highest in the LOW crop diversity systems and lowest in the DAP system.

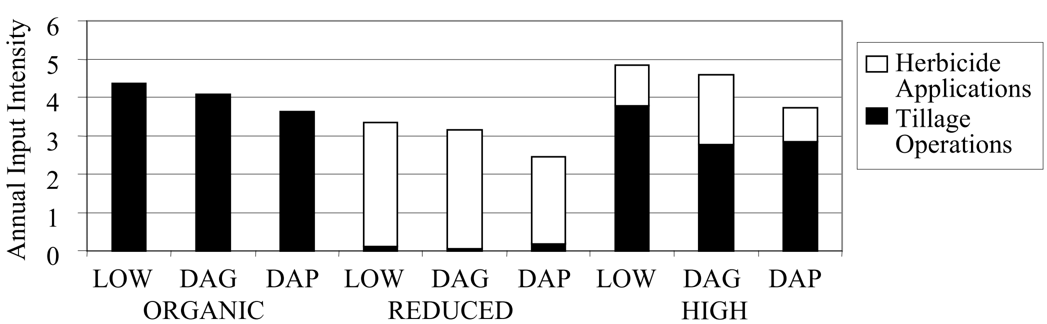

Figure 1. Number of herbicide applications and tillage operations per plot per year.

Details of the study and treatment structure (Ulrich et al. 2001), crop productivity (Brandt et al. 2001) and economics (Zentner et al. 2001) have been summarized in other papers in these proceedings.

Methods

The residual weeds remaining in the plots after in-crop treatment were counted each year from 1994 to 2000. 1994 was the site characterization year in which the entire site was seeded to barley and treated uniformly. Each year, the weeds were identified and counted in twenty 0.5 m by 0.5 m quadrats in each of the 216 plots. Five quadrats were placed randomly within each quarter of the plot.

Frequency profiles were prepared for 1994 and 2000 to illustrate the change in the overall weed community at the site. The percentage of the 216 plots in which the 20 most frequently occurring weeds were present is displayed. Graphs were also prepared to show the change in total weed density, species richness (number of different species per plot) and density of a few selected species in each of the systems over time.

The direction of change of the weed communities in each of the nine treatments is compared using principal response curves (Van den Brink and ter Braak 1997) created using the program CANOCO (ter Braak and Smilauer 1998). This variation on traditional multivariate ordination techniques allows a clear representation of change due to cropping system over time by removing variation due to year and initial spatial factors. Principal response curves are based on redundancy analysis, a constrained form of principal components analysis. In this type of multivariate technique, weed species densities are constrained to be linear combinations of the interaction of system and year. The log abundance of all 48 species that occurred in more than one plot per year are included in the analysis. Year is removed as a covariable. Also, sub-plot is removed as a covariable to remove any initial spatial variation. The interactions between year and the high input low diversity rotation are not included as constraints in the analysis, allowing this system to be used as a reference point. Therefore, change in weed communities in each system is compared against the change observed in the high input low diversity rotation. Monte Carlo permutation tests were carried out to test whether the axes explained more variance than expected. Permutations of treatments were restricted to replicate block to account for the original experimental structure.

A principal response curve is a graph of canonical coefficients for one axis of the redundancy analysis versus time. Alone, this graph indicates the relative difference in the weed community associated with each system as compared to the reference system. The species scores, presented to the right of the principal response curve, enable the reader to determine the relative influence of each species on the principal response curve. Species with the highest absolute values have the largest influence on the trends illustrated in the principal response curve. Species with absolute values less than one are not included on the diagrams in this paper. The log-difference between the weed densities in the control and each system in each year can be determined for each species by multiplying the species score by the desired canonical coefficient.

Results and Discussion

The 1994 frequency profile of weed community composition is dominated by wild oats, wild buckwheat, and lamb's-quarters (Fig. 2). These species occurred in more than 50% of the plots. The profile also contained four perennial species and three volunteer crops. In 2000, the number of weeds occurring in more than 50% of the plots had increased to seven species (Fig. 3). Lamb's-quarters, wild buckwheat, stinkweed, and green foxtail had higher frequencies in 2000 and were the dominant species in the profile. Wild oats occurred at the same frequency as in 1994. The frequency of winter annuals, such as shepherd's-purse, narrow-leaved hawk's-beard and flixweed, had also increased. The diversified crop rotations contributed six volunteer species to the 20 most frequent species. Dandelion was the only perennial species in the 2000 profile.

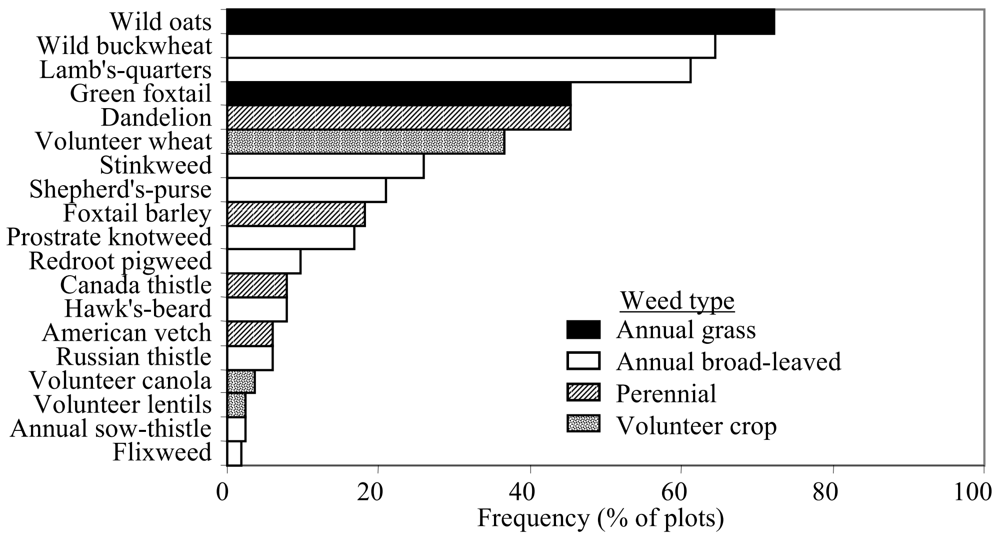

Figure 2. Residual weed frequency in alternative cropping systems study in 1994.

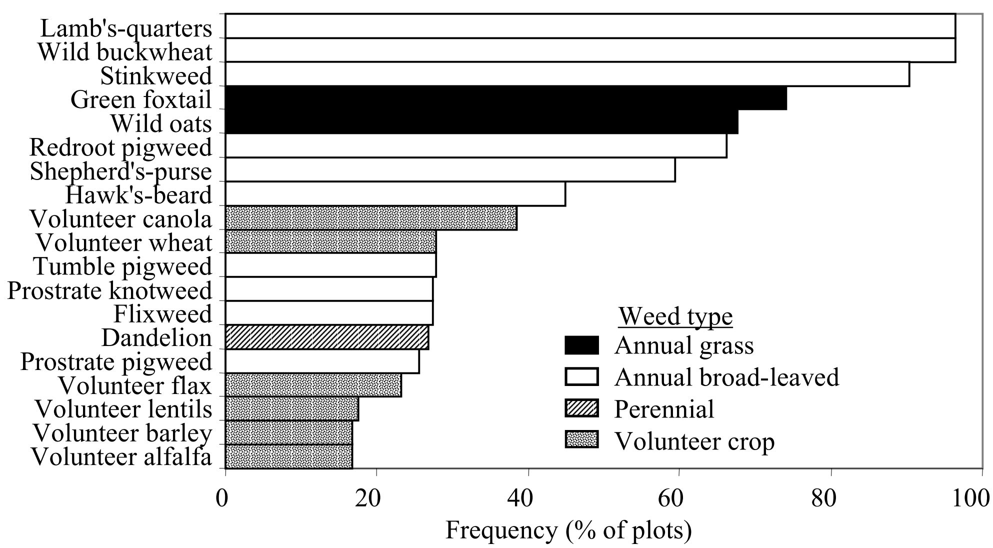

Figure 3. Residual weed frequency in alternative cropping systems study in 2000.

Residual weed densities were very low in the site characterization year (Fig. 4). In general, weed densities increased from 1994 to 1997 in all nine systems, decreased until 1999 and then increased greatly in 2000. This pattern of high and low densities on the site is correlated with the amount of precipitation received in July and August of the previous year (Fig. 5). Normal or above-normal precipitation increased seed production and increased the size of the weed seedbank in the soil. Drier than normal conditions in July and August may result in a reduction of weed seed production and fewer seedlings are recruited the following year. If precipitation in June is higher than normal in the next growing season, many seedlings are recruited from the seedbank and controlled by in-crop weed management. The lowest densities were recorded in the high input system with low cropping diversity and the highest weed density in the three organic input systems. Weed diversity was approximately five species per plot at the beginning of the study and increased to ten per plot in 2000 (Fig. 6). The three high input systems tended to have the least number of species per plot.

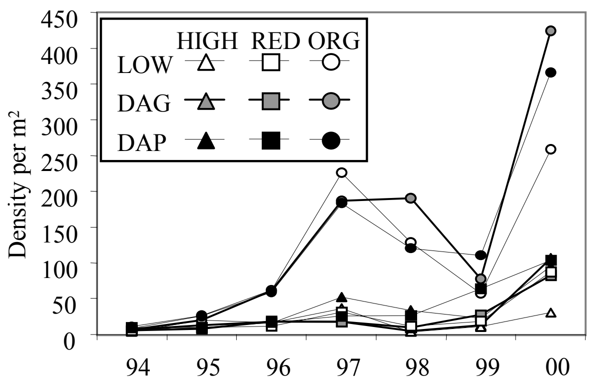

Figure 4. Total weed density in nine alternative cropping systems from 1994 to 2000.

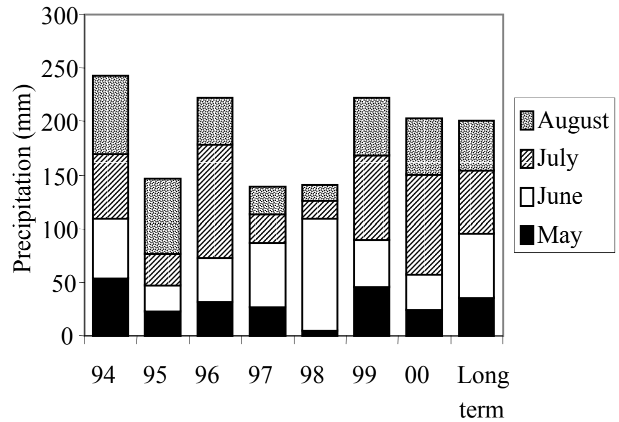

Figure 5. Precipitation in May, June, July and August at Scott Research Farm from 1994 to 2000.

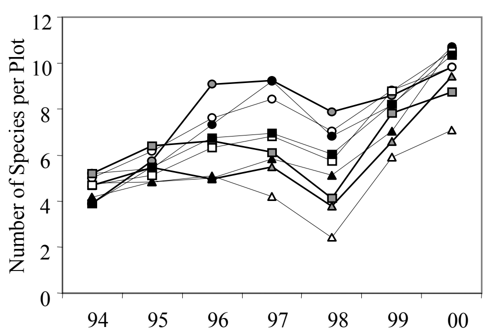

Figure 6. Weed species richness in nine alternative cropping systems from 1994 to 2000.

The multivariate analysis based on RDA explained 41.7% of the variance in the weed community data set. Assessment date (year) and the weed distribution patterns (spatial) accounted for 33.0% and 49.1% of the total explained variance respectively. The treatment structure (systems) accounted for the remainder of the explained variance. Two of the 56 axes were significant and explained 10.3 % of the variance.

Changes in treatment effects through time are clearly shown in the PRC diagrams for axis 1 (Fig. 7) and axis 2 (Fig. 8). The response curve for the reference treatment coincides with the horizontal axis. The PRC diagram for the first axis shows that species composition was similar at the start of the study but changed when the management practices for each system were applied (Fig 7). The largest relative differences in the weed community were found between the reference treatment and the three organic systems and these differences persisted throughout the six years. The curves for the organic systems suggest that the relative differences peaked in 1997 and then remained more or less constant for the next three years of the study. The weed community in the high and reduced input systems closely resembled the reference system.

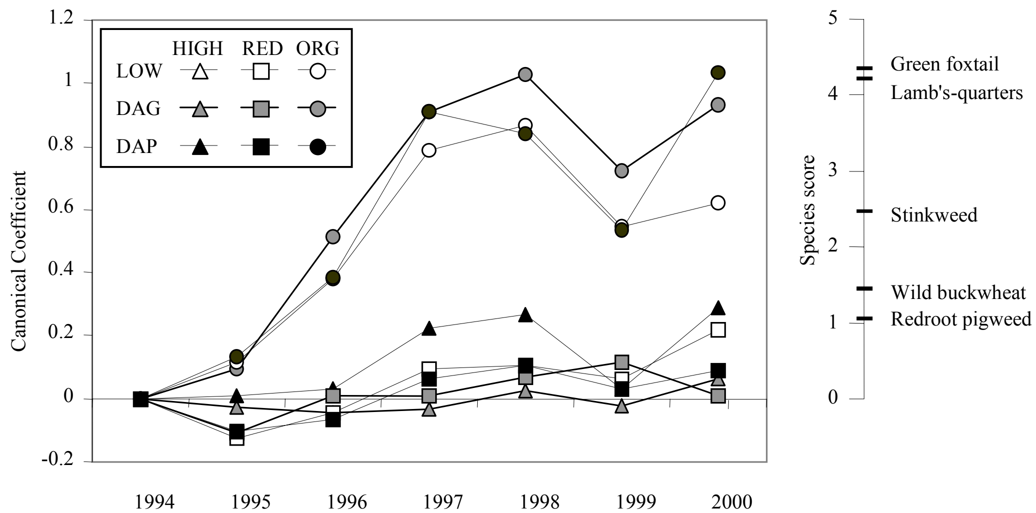

Figure 7. Principal response curve for first axis indicating the effects of alternative cropping system on weed community over time. This axis accounts for 44% of the treatment variance ($P \geq 0.001$).

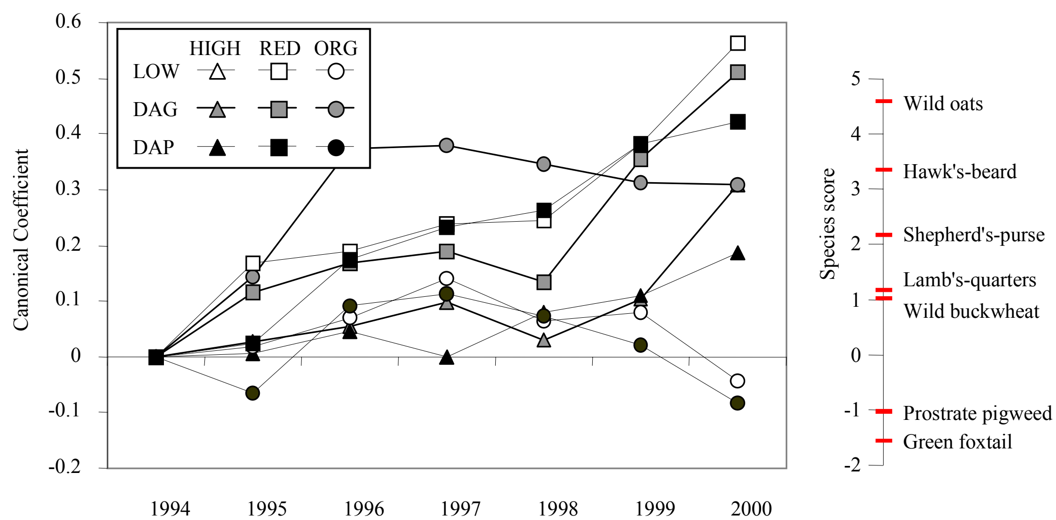

Figure 8. Principal response curve for second axis indicating the effects of alternative cropping system on weed community over time. This axis accounts for 13% of the treatment variance ($P \geq 0.001$).

Weights for species indicate the likelihood that a weed follows the fitted response of the whole community as displayed in a PRC diagram. A positive weight indicates a response pattern consistent with that displayed in the diagram for the overall community and a negative weight indicates an opposite response. The high positive species weights for green foxtail, lamb's-quarters, and stinkweed indicate that the relative contribution of these species to the observed pattern in the weed community is large (Fig. 7). The density of these species is higher from 1997 to 2000 than in the first and second year of the rotation. The density patterns for green foxtail and lamb's-quarters were similar with a drop in density in 1999 whereas stinkweed density dropped in 1998 (Fig. 9). The density patterns for wild buckwheat and redroot pigweed were similar to the previous three species but densities were <10 plants m^{-2} (data not shown).

The PRC diagram for the second axis shows a different and more complex response of the weed community over time than did the diagram for the first axis (Fig. 8). The consistent trend identified across the first six years is a pattern of increasing differences between the reference system and the three reduced input systems. The species that are increasing in the reduced input system also initially increased in the organic systems, peaking in 1997. After 1997, in the LOW and DAP organic systems, these species decreased to moderate levels; however, in the organic DAG systems the high populations were maintained. The most important species on this axis is wild oats. The densities of this species in the reduced and organic systems follow the trends indicated by the second PRC (Fig. 9). Narrow-leaved hawk’s-beard densities contributed to the pattern in the reduced input systems observed on the second PRC. Narrow-leaved hawk’s-beard densities increased in the reduced input DAP system until a peak in 1999. In 2000, the narrow-leaved hawk’s-beard population in this system decreased to a level similar to that observed in 1997. Narrow-leaved hawk’s-beard densities began to increase in the other reduced systems in 1999 and continued to increase in 2000. Change in shepherd's-purse densities did not occur in any systems until 1999 with further increases in 2000. The largest change was observed in the reduced DAP system, but this species increased in all reduced systems. This species increased in the high input DAP and DAG systems, and may be partially responsible for the recent differences between these systems and the reference system illustrated on the second PRC. The increase in shepherd’s-purse in the organic DAP system does not appear to be reflected on the PRC. The relatively small increase in the density of shepherd’s-purse is not as important to this system as the large increase in green foxtail in 2000.

Summary

The PRC analysis identified problematic weed species associated with the cropping systems after six years. Green foxtail, lamb’s-quarters and stinkweed were abundant in the three organic input systems. Wild oats, shepherd’s-purse and narrow-leaved hawk’s-beard were abundant in the reduced input systems. The three organic systems appear to have reached equilibrium after a three-year transition period. The problematic weed species in the reduced systems still appear to be increasing after six years. The research shows the value of assessing weed densities annually and the need to continue weed assessments for the next six-year cycle.

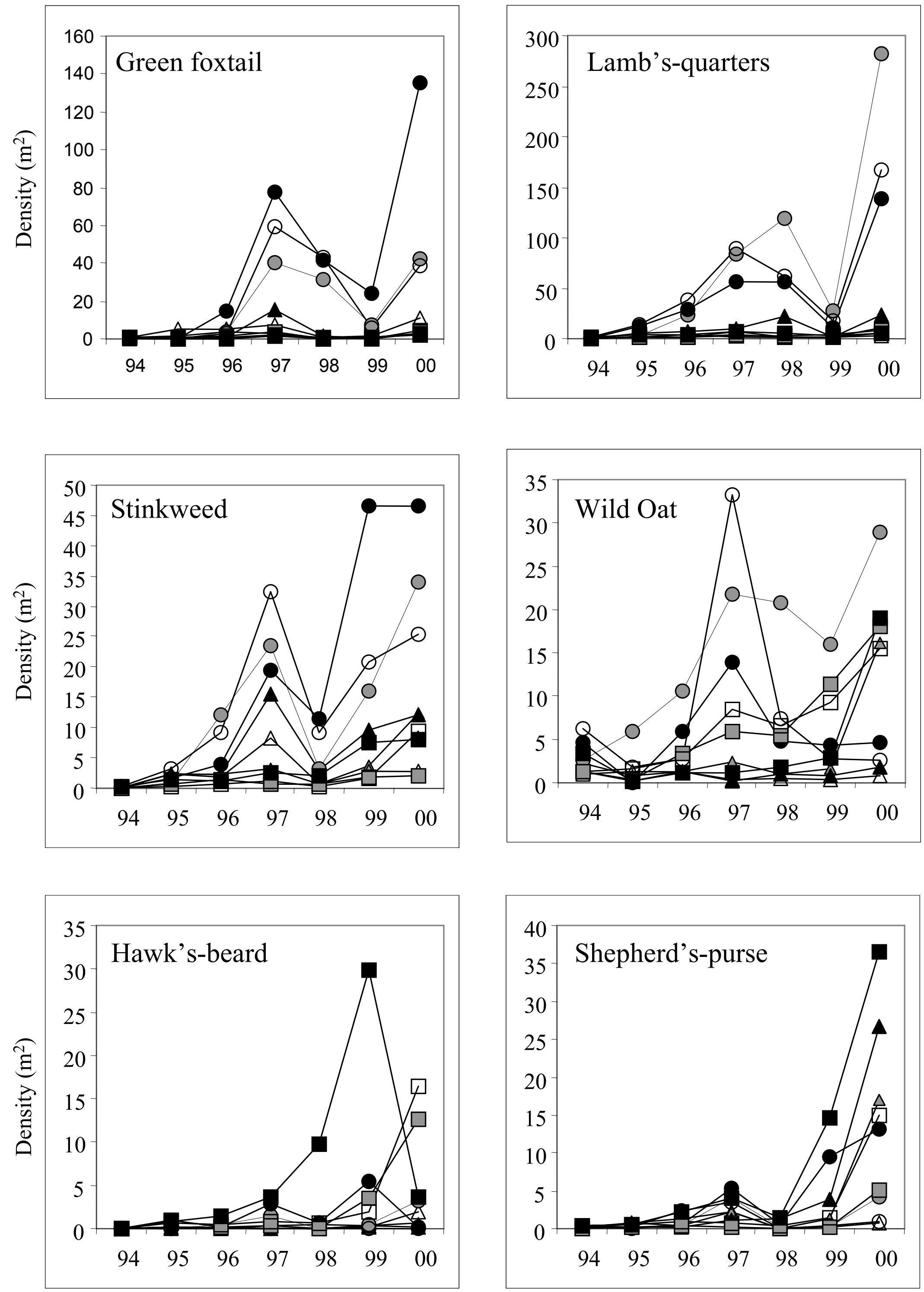

Figure 9. Weed density for green foxtail, lamb's-quarters, stinkweed, wild oat, narrow-leaved hawk's-beard, and shepherd's-purse in nine alternative cropping systems from 1994 to 2000. Systems symbols are the same as Fig. 8.

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